

Quantum Phase Transition in HTSC Thick Films: $\text{YBa}_2\text{Cu}_3\text{O}_x$, $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag-Doped) in a Strong Pulsed Magnetic Field up to 32 T at Low Temperatures (58–100 K), Current Densities and Stress-Effect

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Abstract We have researched the influence of pulsed magnetic fields up to 32 T on the magneto-resistance of thick films (50 Mk) of $\text{YBa}_2\text{Cu}_3\text{O}_x$ and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag-doped) that were produced from synthesized powders. (Figs. 1–9): concentrate with 6.85–6.9 % O_2 and a tail fraction 6.5–6.6 % O_2 .

We observed a linear plot at currents of more than 1 mA at 77 K in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag-doped) at $B > 5$ T and in the concentrate $\text{YBa}_2\text{Cu}_3\text{O}_x$ samples with $I = 1$ mA, $T = 68.2$ K. Pulsed magnetic fields up to 32 T, at $I = 1$ mA had practically no influence on the value of the magneto-resistance in the concentrate $\text{YBa}_2\text{Cu}_3\text{O}_x$ specimens at $T = 57.9$ K and up to 17 T for $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) at 77 K (Meissner effect). However, for $B > 17$ T, $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) at 77 K demonstrates a tendency toward lower resistance.

In the presence to 10 pulses in a cyclic pulsed magnetic field of 32 T, there is a sharp change of magnetic properties of an HTSC that can lead to nontrivial changes in the transition temperature, due to the strong mechanic stresses, sharp change value structure, and because one of the phases becomes superconducting (Figs. 3A, 3B). The behavior of the magnetoresistance of S-N-S contacts in pulsed magnetic

fields is described via the system's parallel resistance, R_n , and the inductance, L_{S-N-S} .

Analysis of microscopic models of quantum phase transitions was made in a granular superconductor in an attempt to explain the results on the studied HTSC-films and to give a physical interpretation to the deduced parameters of some experiments on the basis of “spin (vortex) glass” (vortex ice).

Keywords Pulsed magnetic fields · Thick film · Separation · Heredity · S-N-S-model · Josephson contact · Phase transition · Vortex glass · Flux · V – A characteristic · The concentrate · Tail

1 Introduction

Interest to the intermediate state $H_{c1} < H_m < H_{c2}$ does not weaken from the moment of opening HTSC. It has connected with ambiguous behavior of electromagnetic properties, of the phase structure heredity, by variety of the physics phenomena, including phase transitions in a strong magnetic field [2–12]. Before end full of phase transition take place an intermediate status, in which areas of normal and superconducting phases coexist. The massive superconductor in an intermediate status is stratified on domains of two phases, the sizes of which are less than the size of a superconductor. The equations of thermodynamics allow not addressing to the mechanism to describe the superconductivity phenomenon as of the form of coexistence of electromagnetic and thermal movements of a matter. The condition of convertible superconducting transition is expressed by relation of density-free energy between two phases. The major problems limiting the applications of superconductors based on

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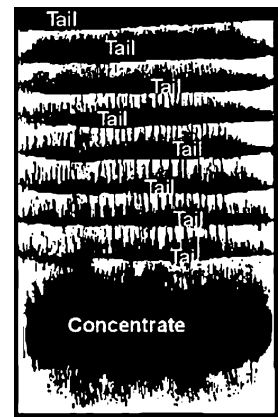
HTSC materials are weak intro-grain and inter-grain couplings. Microscopic defects can act to pin the vortices and maintain the superconducting state to higher temperature. As the origin of weak intro-grain pinning is determined by structural considerations, it is important to choose a material that has strong intrinsic flux pinning capability at high temperatures and magnetic fields. To achieve high transport I_{cr} in a ceramic material, one has to produce effective links between the ceramic grains on one hand and introduce pinning centers on the other [13]. It is assumed that the inter-grain resistance in ceramic $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag), that prevents a high I_{cr} from reducing by the presence of silver in granular spaces of the sample. Knowing how the vortices move and arrange themselves under various conditions, such as temperature, magnetic field, stress-effects, and doping agent (Ag), and how these phenomena are influenced by the physical properties of the material will be critical in controlling the flux motion and maintaining the super current flow in these materials [13, 18, 22, 23, 53, 56–59].

2 Electromagnetic Separation

Samples were made from powders HTSC- $\text{YBa}_2\text{Cu}_3\text{O}_x$ that were separated by the method the electromagnetic separation (EMS) and developed by the author (E. Broide) [14, 15]. EMS admits statistical improvement of the uniformity by decreasing the amount defective zones in the separated powders, number of nonvalid phases, admixtures, and thus, an increase in T_c , I_{cr} , H_{cr} .

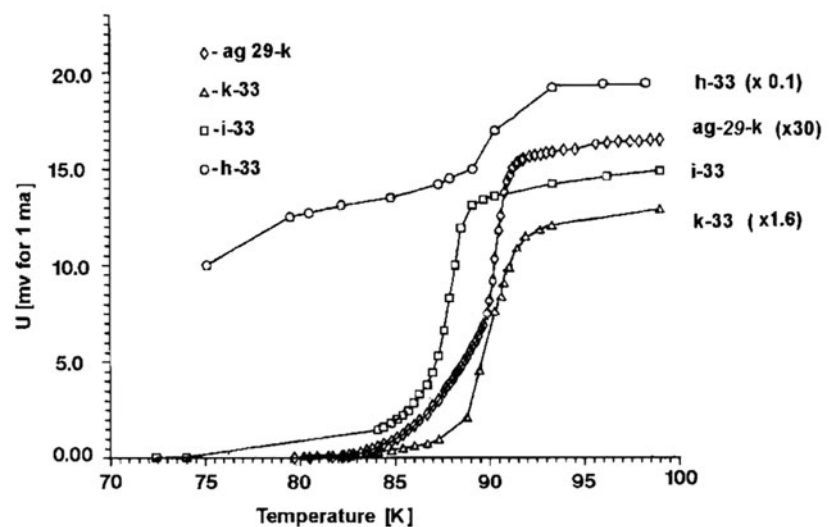
This method is based on the electromagnetic and magneto-hydrodynamic interactions of particles in paramagnetic liquid nitrogen, with doping oxygen and running magnetic fields. The running magnetic fields (RMFs) extract at the enriched powders from mixture those particles (a concentrate

Fig. 1 Visual picture of HTSC after EM-separation (concentrate-dark mater, treated-tail)



granules with more percent of oxygen- O_2) that have a high critical current with fewer defects. RMFs have switched on after the cooling of the powders of uniform size in liquid nitrogen. The separation has carried out in an RMF of frequency 50–200 Hz and amplitude 0.05–0.15 T, by a linear asynchronous motor. Two different fractions of powders have been obtained after the successfully conducted EMS (Fig. 1): the concentrate is a part of the SC-powders with quantity O_2 in the interval 6.85–6.95 % and temperature of SC-transition more than 77 K. Under influence of RMF, it move up on inclination endways. “Tail”-bad part SC-powders have tetragonal structure with the oxygen stoichiometry less than 6.6 % O_2 and, naturally, T_c less than 77 K. The tail is moved on the inclination downwards. Figures 1, 2 show that superconducting powders with optimal quality “concentrates” are actually enrichment, and the “tail” needs an additional thermochemical treatment. $\text{YBa}_2\text{Cu}_3\text{O}_x$ attracted to the magnetic pole is tail, with the oxygen stoichiometry less than $\text{O}_2 = 6.6$ %, and possesses tetrahedral structures (the value of x —the original mixture ranged from 6.4 to 6.9 %) and ferromagnetic properties.

Fig. 2 Difference of the resistance of thick films made from powder before and after the Separation of $\text{YBa}_2\text{Cu}_3\text{O}_x$ and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag): source (\square -i-33), concentrate (Δ -k-33), tail (o-h-33), the part the powder having the worst properties, and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) (\diamond -29-k)



$\text{YBa}_2\text{Cu}_3\text{O}_x$ attracted to the magnetic pole is tail, with the oxygen stoichiometry less than $\text{O}_2 < 6.6\%$, and possesses tetrahedral structures (the value of x —the original mixture ranged from 6.4 to 0.95 %) and ferromagnetic properties. In the case where thermodynamic equilibrium was interrupted during synthesis (tail) and the process the saturation oxygen is not realized, one can observe the striped (similar to the ferromagnetic) picture, which was preserved after shutdown of the RMF.

3 Magneto-resistance HTSC at Change of Conditions H, I, T

We have investigated thick film samples of $\text{YBa}_2\text{Cu}_3\text{O}_x$ ($\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) with thickness 50 μm , at the temperature interval 50–77 K and current $I_{sc} = 1\text{--}10$ mA in the external interval magnetic fields 32 T ($H_{c1} < H_m < H_{c2}$), which is one of the important parameters for applications of high- T_c superconductors. The thick-films were made by paint method on the MgO-substrate in the presence of organic binding materials by heating the powder from product separation: source, concentrate, and tail. Specimens (from HTSC-powders after separation) are demonstrating heredity of the structure and electric properties, particularly in T_c , I_{cr} , H_{cr} . This fact is demonstrated in Fig. 2, where the effect of changing electrical properties after electromagnetic separation for films $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) 30 times more as in nondoping specimens $\text{YBa}_2\text{Cu}_3\text{O}_x$. The polycrystalline $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) films have a great amount of isolated grains and are coupled via a large concentration of Ag on the grain boundaries. Explanation of the magneto-resistance behavior within this physical model of the superconductors comprises a set of constituents, among which there are:

- a change of impedance of Josephson like contacts between granules and structural domain,
- destroying the superconducting pairs of charge carriers,
- an excitation and movement of vortexes,
- formation of an N-state domain.

So, a detailed studying behavior of properties is necessary, in particular, the dependence of magneto-resistance on of a magnetic field, the values of electrical currents, of doping agent (Ag), and mechanical stress, with the purpose to throw light onto a rather complex picture of phase transitions of HTSC and to understand better the strong pinning effect on $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) composites. An important condition for good flux pinning properties is the creation of effective centers on the surface of granules [13].

This doped phase YBaCuO_x (Ag) shows a longer c axis than regular YBCO ceramic material and forms a network of superconducting “rings” localized on the YBCO large grains. This network is probably the source of the high flux-trapping phenomenon in the composite material [13].

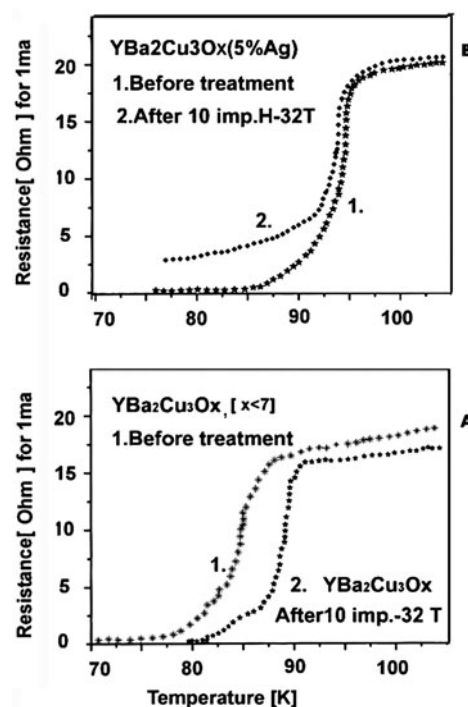


Fig. 3 Phase transitions in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (tail-% $\text{O}_x < 6.7\%$) and in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) under mechanical stressing after 10-pulse $B = 32$ T

We discovered that subjecting the thick film samples of $\text{YBa}_2\text{Cu}_3\text{O}_x$ to 10 pulses, a cyclic pulsed magnetic field of 32 T leads to a significant increase in T_c (Fig. 5A). Therefore, irreversible changes in the superconducting parameters occur. The films had an oxygen deficit 6.6–6.8 % O_2 . The exposure to the magnetic field was performed at the tetragonal, orthorhombic transition temperature 77 K. Initially, temperature SC-transition- T_c was 74 K. After the treatments by the strong pulses of magnetic fields, T_c had increased to 80 K (Fig. 3A).

In the presence of a magnetic field, there is a sharp change of magnetic properties of an HTSC, which can lead to nontrivial changes in the transition temperature due to the strong mechanic stresses, sharp change value structure, and because one of the phases becomes superconducting. The force acting on a state of transformation in a magnetic field arises from a difference of magnetic susceptibilities of the two contacting phases. It is reasonable to suppose that the observed effect is caused by the martensitic nature of the transition to a tetra-orthorhombic structure in $\text{YBa}_2\text{Cu}_3\text{O}_x$, the instability of this compound near the SC-transition in high magnetic field, and strong mechanic stresses, which result in the displaced deformation in the tetragonal phases [66, 67].

Based on the theory of elastic deformation, one can conclude that if the amount of martensitic phase for $\text{YBa}_2\text{Cu}_3\text{O}_x$ is $x < 6.8\%$, we are dealing with an increase in the length

Fig. 4 The magneto-resistance behavior of $\text{YBa}_2\text{Cu}_3\text{O}_x$ -thick film (was made from concentrate-(33-k) at the temperature 60–67 K and $I = 2$ mA)

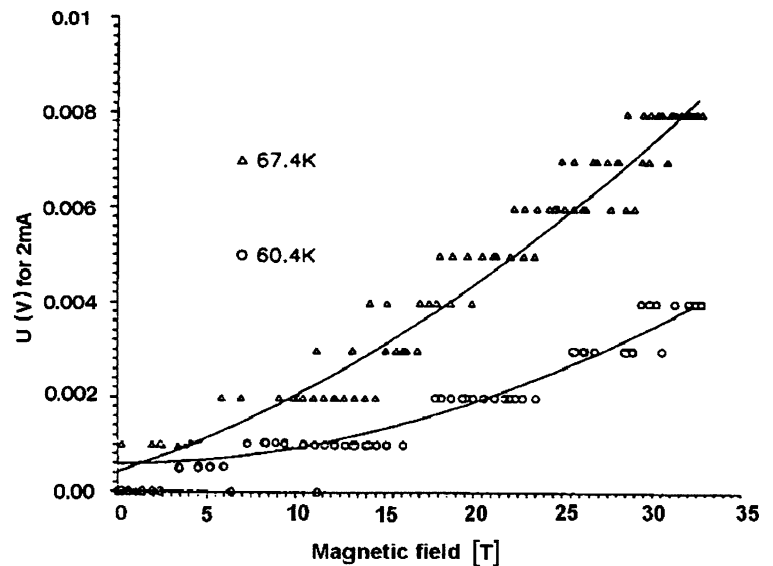
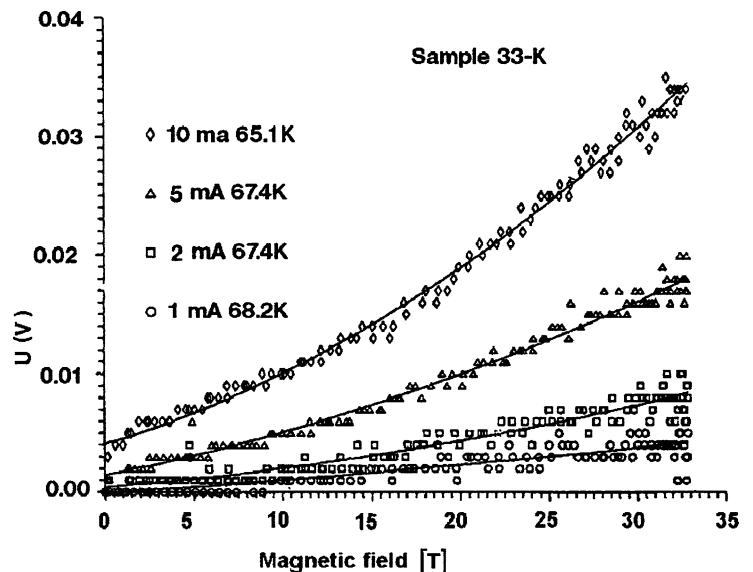


Fig. 5 The magneto-resistance behavior of $\text{YBa}_2\text{Cu}_3\text{O}_x$ -thick film (was made from concentrate-(33-k) at the temperature 65–68.2 K and different currents)



of the orthorhombic axes in the elementary cell of a lattice; this leads to a growth in the amount of orthorhombic phases and thus to an increase in the value of the superconducting transition temperatures (Fig. 3A). On the other hand, in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag), the processing by strong pulsed magnetic fields leads to dynamic mechanic stresses, which increases the amount of tetragonal phases; this leads to a lower temperature of the superconductivity transition (Fig. 3B). These transitions of superconductors in a normal phase and conversely are of the first order [38, 53, 55].

Experimental data, adduced in this article, demonstrate the influence of value of a magnetic field, temperatures, impurities, currents force, and stresses on the picture of physical properties near temperature phase transitions (SC-normal metal) in interval magnetic fields $H_{c1} < H_m < H_{c2}$.

If the weak links in the granular film are subjected to a magnetic field that may be connected with correlation phase in orders parameter the system, there is a condition occurrence of volume superconducting properties and to influence on their kinetic inductance and resistance, as am seeing from circuit on Figs. 10 and 11 [19].

The superconductor in an intermediate status is stratified on domains of two phases, the sizes of which are less than the size of a superconductor. In real nonuniform superconductors, probably abnormal multi-coherent areas with high critical temperatures are present, which can grasp a magnetic stream as a superconducting ring (Fig. 11) [62]. In that case, there is a so-called phenomenon of the frozen stream, the existence of the diamagnetic moment in the absence of an external field [68]. Results of experiments argue in favor of the existence of a true phase transition in the high-

Fig. 6 The magneto-resistance behavior of $\text{YBa}_2\text{Cu}_3\text{O}_x$ (33-k)-thick film at the temperature 57.9–68.2 K and $I = 1 \text{ mA}$

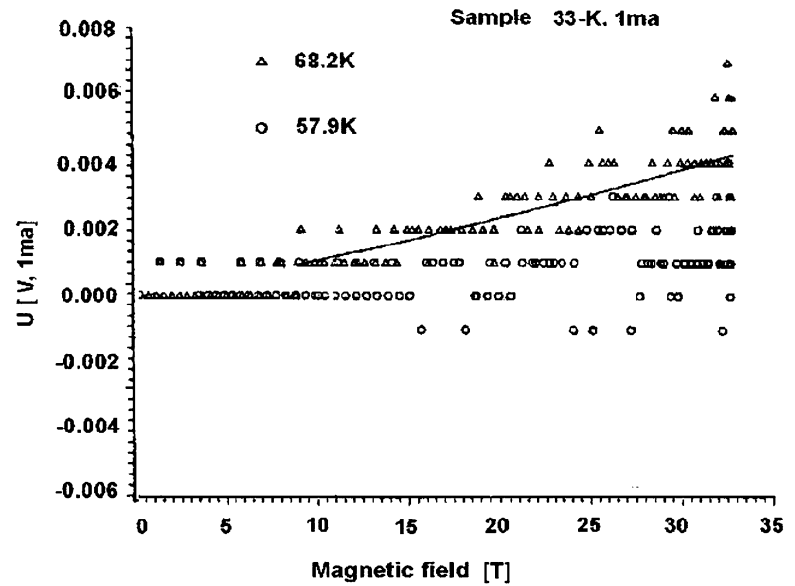
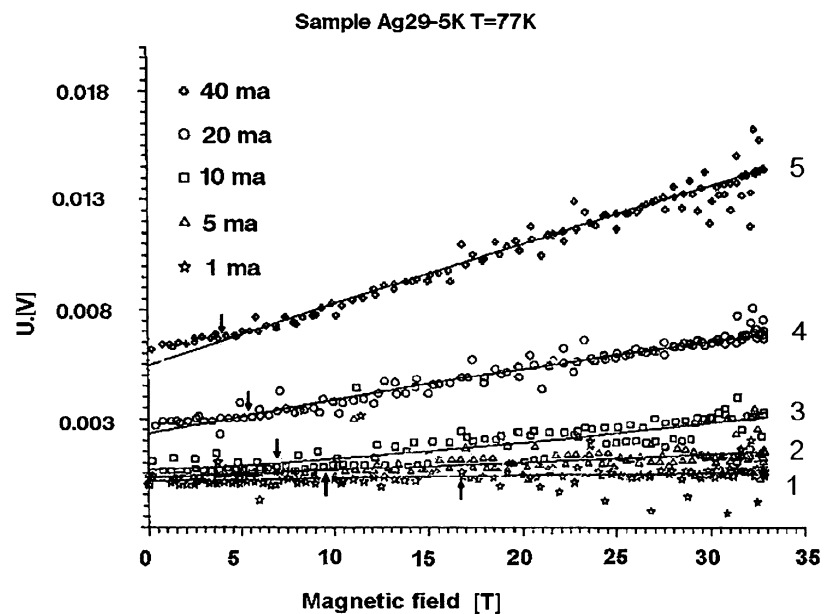


Fig. 7 The plot of resistance with magnetic field of $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag-doped) thick films at 77 K



field vortex state from a low-temperature superconducting vortex glass (ice) phase into a disordered high-temperature vortex fluid phase. Pinning of vortices due to impurities or other defects destroys the long-range correlations of the vortex lattice, probably replacing it with a new vortex-glass (ice) phase that has spin-glass (ice-like off-diagonal long-range order and true superconducting) [56]. Also, a disorder-induced transition was found from the three-dimensional Bragg glass (ice) to a quasi-two-dimensional vortex glass (ice), accompanied by an abrupt change of the interlayer coherence with increasing field. The former one is identified as an intra-layer depinning transition as premelting, which subdivides the glass (ice) phase into two phases. The intermediate glass (ice) melts with inter-layer decoupling of vortex

lines, implying the loss of interlayer long-range coherence [53]. These two-phase boundaries agree with experimental data on $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) and $\text{YBa}_2\text{Cu}_3\text{O}_x$.

The superlinear behavior in high magnetic fields was attributed to the opening of a spin gap under magnetic field [27, 39–45, 61, 68, 70].

Properties of disordered granular superconductor films consisting of HTSC-grains of size comparable to zero-temperature bulk superconducting coherence length embedded in a non-SC metal, Ag, was studied (Figs. 2–12). Turn-on of a magnetic field moves up a sample into the next form of SC-films, preliminary cooled to $T < T_c$ in a status of a “superconducting glass (ice),” which, as well as usual frustration spin glass (ice), when pseudo-backed, should choose

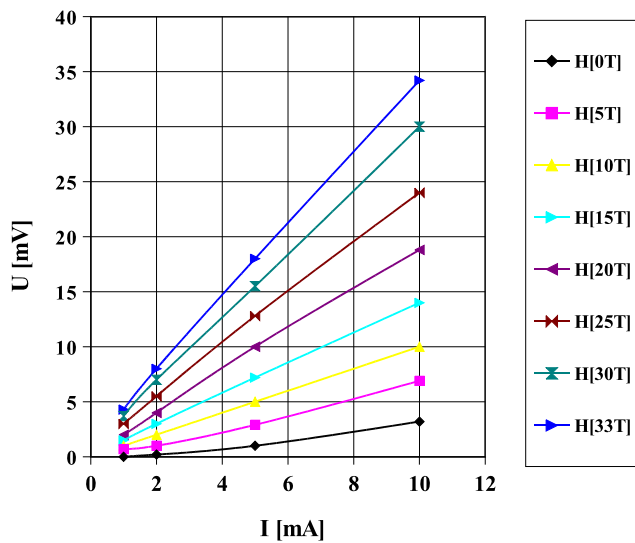


Fig. 8 Volt-ampere characteristic in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (33-k)-thick film at 57.9–68.2 K

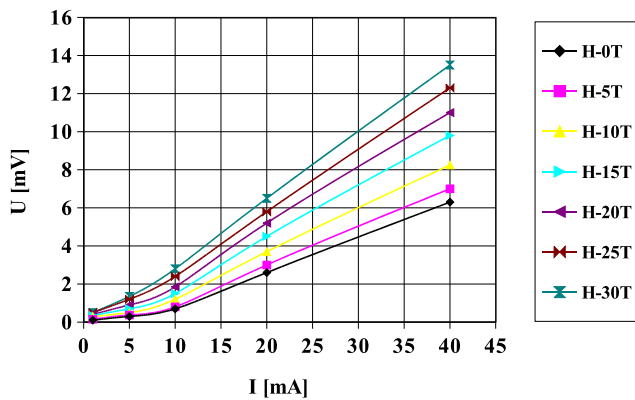
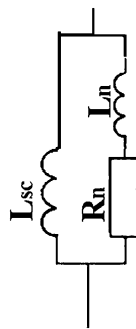


Fig. 9 Volt-ampere characteristic in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag-doped) thick films at 77 K

Fig. 10 Equivalent circuit S-N-S contact



between two orientations, and thus this state of sample is metastable [1, 53, 55–59].

The normal, as well as the superconducting state, is strongly dependent on doping and thus on the carrier concentration. In order to increase the temperature HTSC-transition in high magnetic fields, considerable efforts were

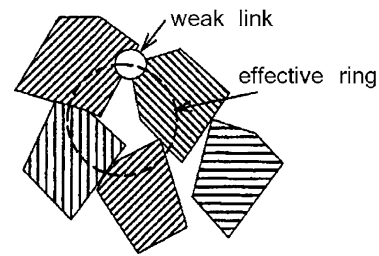


Fig. 11 Weak link in granular superconductor films

directed by the creation of strong pinning centers, for example, for $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag). Value state parameters, the temperature, T , magnetic field, H , electrical current, I_{sc} , and stress-effect are defining quantities of the flux motion and maintaining the super current flow in these materials [37].

A magneto-resistance in film $\text{YBa}_2\text{Cu}_3\text{O}_x$, $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) under magnetic pulse up to 32 T is described with the help of phenomenological models of parallel systems of normal resistance (R_n , L_n)-inductance of superconducting branches (L_{sc}) and its V – A characteristic. Concurrently, the microscopic theory of the transition granular superconductor allows us also to give us the quality explanation effects [1, 16, 21–36, 46–64, 68].

4 S-N-S Model

Thin layers (of thickness about several Å) in a thick film are different from grains in chemical structure and phase structure, typically exhibit weak connections, and are of the inter-granular Josephson structure (usually, of S-N-S type). At the same time it illustrates the equivalent “ring,” which constitutes the path of the current including the weak link (Fig. 11). Probably, also intragranular Josephson transitions exist (even on planes twining between planes superconducting them). In National High Magnetic Field Laboratory, USA (David C. Larbalestier, Alex Gurevich, Mark Rozchowski), high-resolution electron microscopy on nanoscales (0.1–10 nm) has revealed a detailed atomic structure of the grain boundaries, dislocation cores and changes, due to control of overdoping of the grain boundaries (GBs) of $\text{YBa}_2\text{Cu}_3\text{O}_x$.

These issues determine the behavior of vortices on GBs that are of prime importance for the current carrying capability of HTSC. It demonstrated the existence of mixed Abrikosov–Josephson vortices at low-angle GBs and measured for the first time their core lengths and the intrinsic value of I_{cr} . Properties of disordered granular superconductor films consisting of HTSC grains of size comparable to zero-temperature bulk superconducting coherence length embedded in a non-SC host were studied by

means of a randomly diluted Josephson tunnel junction S-N-S model. Change of the total picture of the magnetoresistance (Figs. 2–12) will completely determine the proportion of the superconducting and normal components of the sample in frame S-N-S-modes.

Superconductor–normal metal–superconductor (S-N-S)-junctions have current–voltage characteristics (C-V-C) with rich peculiarities. Given certain parameters of the junction C-V-C, S-N-S-junctions demonstrate a current peak at small voltage, excess current, a subharmonic gap structure, and the negative differential resistance at low bias voltage [69].

The behavior resistance of an S-N-S contact under pulsed magnetic fields in granular films in the studied intervals of high alternating magnetic field may be described with the help of three system parameters: the normal resistance and inductance (R_n , L_n) and the superconducting inductance (L_{sc}), which are connected in parallel [16, 17, 20, 71]. The equivalent circuit of a superconductor consists of two parallel branches, a right-branch current caused by normal electrons, with superconducting electrons in the left branch (Fig. 10).

The quantities of the active (resistive R_n) and reactive (inductive L_n , L_{sc}) currents depend on the quantity of normal and superconducting electrons present in the material and their mobility. Because electrons have effective mass, they lose energy due to scattering, and the result is a larger resistance (R_n , L_n , L_{sc}). The direct current (DC) resistance in the left branch is zero, whereas the resistance in the right branch has a finite value. As a result, the DC conductivity in the material occurs only in the superconducting branch and without energy dissipation. Superconducting electrons, like normal electrons, have effective mass, m_e , and contribute to the creation of the kinetic inductance, L_{sc} , of the sample, as a manifestation of their kinetic energy, ESC, which is stored in the superconductor of the form of the kinetic inductance, L_{sc} .

Thus, superconductivity is not only a high conductivity (i.e., a large imaginary conductivity), it is a kinetic inductance, and the electron's energy is:

$$E_{sc} = \frac{1}{2} n_{sc} m_e v_{sc}^2 d S = \frac{1}{2} L_{sc} I_{sc}^2, \quad (1)$$

$$I_{sc} = e n_{sc} v_{sc} S, \quad (2)$$

$$L_{sc} = m_e \frac{d}{n_{sc}} e^2 S. \quad (3)$$

Here n_{sc} is the electron density per unit of volume, m_e is the effective mass, v_{sc} is the velocity of carriers of charge, I_{sc} is the electrical current, d is the specimen length, S is the cross-sectional area, and L_{sc} is the kinetic inductance. The kinetic inductive, L_{sc} , is very small, because the electron density n_{sc} is large. If the material is placed in an alternating magnetic field, the current split between the two branches is inversely proportional to their resistivity, and the current

will flow the two branches. The current flow in the right-hand branch is created by normal electrons that have dissipation and cause the ohmic resistance. If H is increased, the vortices become more closely spaced, and their cores start to overlap. At H_{c2} , the vortex lattice and the pairing of the electrons disappear, and the material becomes normal.

The depth of penetration of a magnetic field, λ_j , in samples can be expressed as

$$H = H_0^{-x/\lambda}, \quad (4)$$

where x is the distance from a surface, H_0 —the intensity of a field on a surface, λ —a constant determining the depth of penetration of a magnetic field in a superconductor:

$$\lambda = m_e v_{sc}^2 / 4\pi n_{sc} e^2, \quad (5)$$

where n_{sc} is the electron density per unit of volume participating in a superconducting current with effective mass m_e . Below T_c is the temperature of S_c -N-transition, and the circuit impedance of the superconductors films, z_j , with S-N-S-links, will be defined by the inductance of contacts L_{s-n-s} (L_j), critical current I_{cr} , and by the frequency of the alternating magnetic field ω and normal resistance R_n [16, 71]:

$$z_j(H) = R_n \quad (T > T_c), \quad (6)$$

$$z_j(H) = i\omega L_{sc} + \omega L_{sc}/R_n \quad (T < T_c). \quad (7)$$

For $T < T_{cr}$ and pulse magnetic fields in the interval $H_{c1} < H_m < H_{c2}$ and $B_{imp} > 5$ T, the critical current I_{cr} for individual Josephson contacts of $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (33-K) samples ($I = 1$ mA, $T = 68.2$ K) to SC-space falls with growth of magnetic fields approximately linearly (see Figs. 5–7):

$$z_j \approx B \quad [22], \quad (8)$$

where z_j is the impedance of the superconductor films, B is the induction of magnetic fields.

If to turn on intense magnetic field or to change temperature and the magnitude current flowing through the sample, substantially will be varied all electromagnetic characteristics on superconductors and for the normal branch— $H_{c1} < H_m < H_{c2}$, which will be determined ultimately the presence the heterogeneity properties.

The superconductivity can be destroyed not only by heating or external magnetization but and its own magnetic field, which transmitted through the superconductor strong electric current. The corresponding critical current density should be such that in the absence of an external magnetic field of its own on the surface would be equal to the critical one. The external layer of wire is in a normal condition, and that the interior—in the interim, with alternating layers of the two phases, perpendicular, the wire axis. In type-II superconductors can be observed surface superconductivity, associated with the formation of nuclei of the normal phase in the surface layer are perpendicular to the wire axis. The

current density of superconducting thin films is very sensitive to their geometry and uniformity. Although the highest current density is attained at the edges of the film, the appearance of the normal phase nucleation is possible in the middle of the inhomogeneous film and their subsequent thermal spread. Field is specified characteristics of the electronic structure and the current—defects in the crystal structure of the material: heterogeneous in its composition, vacancies, dislocations. In this case, the Lorentz effect on them of the intrinsic magnetic field of current flow is not enough for their first job irregularities. As the current density increases and the magnitude of the Lorentz force. Finally, at the current density is equal of critical value, begins movement of Abrikosov vortices, as results contacts with irregularities of the structure. In real inhomogeneous superconductors, there may be abnormal connected domains with high critical temperatures that can capture the magnetic flux-type superconducting ring. In this case, there is a phenomenon called the frozen flow is manifested in the existence of the diamagnetic moment in the absence of an external field [68].

In between there lies an intermediate state, in which the areas of normal and superconducting phases coexist. The transition to a normal phase is completed when the field in all points on the surface of a superconductor exceeds the critical value, H_{c2} . The bulk of the superconductor in the intermediate phase is stratified into domains of two phases, with sizes less than that of the superconductor. The interest in the intermediate state $H_{c1} < H_m < H_{c2}$, has not weakened from the time of the discovery of HTSC. It is connected with the ambiguous behavior of the electromagnetic properties, the phase structural heredity, and with a variety of other physical phenomena, including phase transitions in a strong magnetic field. The behavior on SC-film in a magnetic field demonstrates quantum phase transition in high pulse magnetic fields (Figs. 5–9). The microscopic explanation of the physics for $H_{c1} < H_m < H_{c2}$ is inconsistent. The equations of thermodynamics allow not addressing the mechanism behind the superconductivity as a form of coexistence of electromagnetic and thermal movement of a matter. The condition of a continuous superconducting transition is expressed by the relation of the free energy density in the two phases. The existence of superconducting materials in the interval $H_{c1} < H_m < H_{c2}$ is correspond to a state of the minimal free energy. The intermediate state is thermodynamically stable because the magnetic energy of superconductors falls by reason of the granulation into superconducting layers and a corresponding increase in surface energy. Phase transitions first order to a normal phase below H_{c2} and are accompanied by heat loss from the crystal lattice, decreasing free energy and superconducting temperature [68]. Thus, it is necessary to undertake a detailed study of the behavior of these properties, in particular magneto-resistance, value of electrical currents, of doping agent (Ag),

and mechanical stress, with the purpose to throw light on the rather complex picture of phase transitions of HTSC and to understand better the strong pinning effect on $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) composites. An important condition for good flux pinning is the creation of effective centers on the surface of granules [13].

In high-pulse magnetic fields in $H_{c1} < H_m < H_{c2}$ there are phases near SC-transition:

- Meissners phase, 1—vortex lattice phase, 2—vortex fluid I, 3—vortex fluid II, 4—normal phase [53, 55].
- Meissners phase, $R = 0$: Fig. 4 $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $T = 60.4$ K, $I_{sc} = 2$ mA up $B < 2.5$ T. Figure 5 $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $T = 68.2$ K, $I_{sc} = 1$ mA, $B < 5$ T. Figure 7 $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag), $B < 15$ T, $I_{sc} = 1$ mA, Fig. 6 $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $T = 57.9$ K, $I_{sc} = 1$ mA and $B < 15$ T.
- I. Figure 7 for $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) near $T = 77$ K, $I = 5$ –10 mA and Fig. 6 $\text{YBa}_2\text{Cu}_3\text{O}_x$ -68.2 K at $I_{sc} = 1$ mA up to $B < 7$ T, also Fig. 5 $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $B < 5$ T for $I = 2$ mA, $T = 67.4$ K, Fig. 4 $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $B = 2$ –7 T for $I = 2$ mA, $T = 60.4$ K, Magneto-resistance dependence is not realized, as a consequence of the rising 3d Abrikosov vortex lattices.
- II. Figure 7 for $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) in the intervals of current $I_{sc} = 20$ –40 mA, $B = 0$ –5 T. In Fig. 5 for $\text{YBa}_2\text{Cu}_3\text{O}_x$ at $I_{sc} = 5$ mA, $B < 7$ T and $\text{YBa}_2\text{Cu}_3\text{O}_x$. $I_{sc} = 1$ –2 mA and $B > 7$ T, $T = 68.2$ K. The magneto-resistance dependence has weak linear characteristic, which is accompanied with inter granules the lattices-vortexes melting process. This is phase transition of second order that exists in a magnetic field.
- III. For $\text{YBa}_2\text{Cu}_3\text{O}_x$ near $T = 65$ –68 K, $I_{sc} = 5$ –10 mA, $B > 5$ T, the nonlinear dependence magneto-resistance (Fig. 5) and linear dependence V – A characteristic (Fig. 8). In this field, SC-to normal phase first-kind transition in magnetic fields in the interval 5–10 T is demonstrated.
- IV. Figure 7 for $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag), $B > 5$ T, and $I_{sc} = 10$ –40 mA is put into effected linearly magneto-resistance dependence and nonlinear V – A characteristic (Fig. 9). This situation is the result of vortex lattice melting and phase transition in inter-grain-into-grain lattice.
- (What is nature phase transition is a problem for physics HTSC [18].)
- V. In Fig. 5 it is illustrated that $\text{YBa}_2\text{Cu}_3\text{O}_x$ at current interval $I_{sc} = 1$ –10 mA depends on high pulse magnetic fields, and in Fig. 7, $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) for electrical current $I_{sc} = 1$ –40 mA demonstrates all phase transitions (I – V -position) that exist by theory of liquid glass (melting hard ice). This gives us pictorial presentation about its essential part in the fundamental properties of HTSC materials. Similar influenced effect of lowered temperatures in $\text{YBa}_2\text{Cu}_3\text{O}_x$ and doped

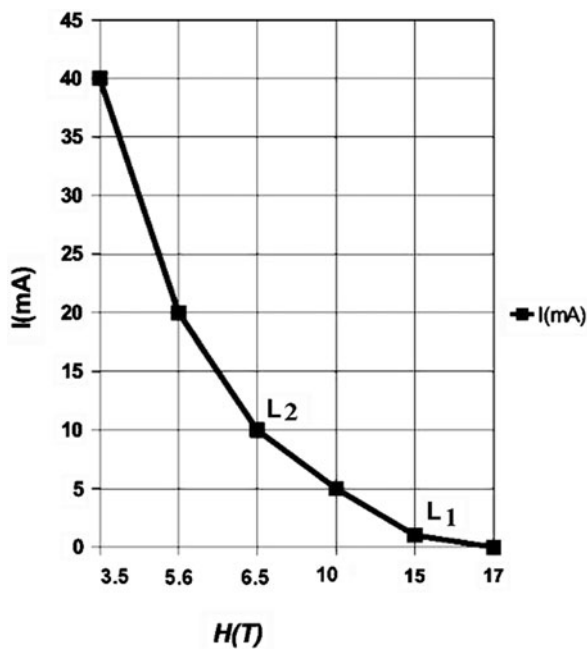


Fig. 12 The dependence of beginning melting last phase in vortex lattice of H_{L1} and H_{L2} on the value of electrical current in films $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag)

Ag on the magneto-resistance to 32 T in $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) was discovered, which causes the impedance drop Josephson contacts and increased critical current (Fig. 12).

- VI. Figure 7 for $\text{YBa}_2\text{Cu}_3\text{O}_x$, $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) at $I_{sc} = 1$ mA, $T = 77$ K, $B > 17$ T (external field for $H > H_{cr}$)—demonstrates tendency for negative character resistance, where vortex-lattice phase can melt due to thermal fluctuations, magnetic fields, and electrical current. Authors of the articles [25] and [65] I.S. Beloborodov, K.B. Efetov, G. Shaikhutdinov, and D. Bataev explain this nontrivial sensitivity to the magnetic field and the behavior of electrical resistance $R(H)$ by granular characters of high-temperature superconductors, due to the effect exerted by dipole moments of high-temperature superconductor grains on the effective intergranular field. At low temperature, the pairs do not contribute to the macroscopic transport, but their existence can drastically change the conductivity. Growing the magnetic field, one destroys the fluctuations, which improves the metallic properties and leads to the negative magnetoresistance. The applied magnetic fields reached 17 T, which was more than sufficient to destroy also the superconducting gap in each grain. The tunneling amplitude between the grains is assumed to be large, such that the system without electron–electron interactions would be a good metal and would not be sensitive to a magnetic field [25].

Figure 12 is demonstrating the dependence of the beginning melting in last phase vortex lattice on the value of electrical current (I_{cr}) and magnetic field (H) in films $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag).

The attention of the above interpretation of phase transition between normal metal and superconductor, which was adopted in the assumptions, can execute the analysis of magneto-resistance behavior and V – A characteristics of $\text{YBa}_2\text{Cu}_3\text{O}_x$ and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) films and give us a possibility to identify quantum phase transition in high-pulse magnetic fields (Figs. 2–9 and 12).

5 Conclusions

Many people speculate that HTS results from the proximity of a QPT of high- T_c cuprates in the underlying normal state both from the theoretical and experimental perspective. The existence, location, and nature of such a QPT was long been obscured by the superconducting phase; however, normal state behavior at low temperatures emerges once the HTSC phase is suppressed with intense magnetic fields [27]. Our measurements and other experiments on the YBaCuO_x and $\text{YBa}_2\text{Cu}_3\text{O}_x$ (5 % Ag) superconductors are discussed in light of these results. It is possible to see from experiments (Figs. 4–9) the situation in phase vortex lattice, due to thermal fluctuations, magnetic fields, stress-effect, electrical current, and dependence from doping Ag. Similar influence of lower temperatures and doping Ag on the magneto-resistance was discovered, and using S-N-S models, it is explained by the impedance falling in Josephson contacts and increasing critical current in $\text{YBa}_2\text{Cu}_3\text{O}_x$. Also, increasing the values of high-pulse magnetic field and electrical currents leads to distortion vortexes, superconductor pairs, and melting vortex lattice (Figs. 4–6 and 12).

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Appendix: Application

- I. Vortex hard lattice—spin-glass phase. (Hard vortex ice)
- II. Vortex phase—fluid I. The intermediate glass melts with inter-layer decoupling. (Internal melting vortex ice).
- III. Intro-layer decoupling of vortex glass lines (vortex phase—fluid II) (Intro-melting vortex ice).

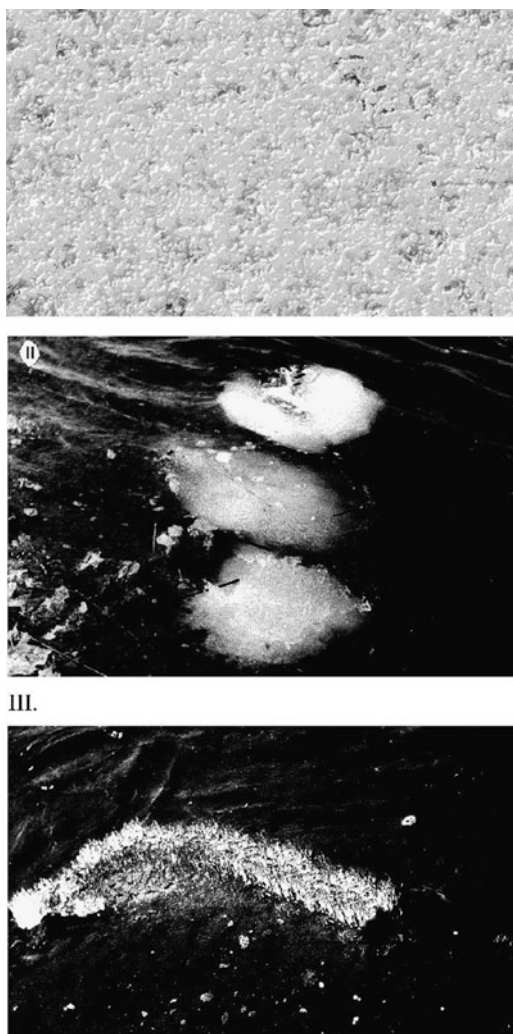


Fig. 13 The frustration spin-lattice glass phase (melting vortex ice)

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